

# Interactive 3D-Visualisation of Glacier Changes based on the Swiss World Atlas interactive

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**Abstract.** Glaciers are sensitive to changes in climate conditions and they react with clearly visible consequences. The most common way to map glacier changes is the traditional static 2D map but the representations in a 2D map are limited. The Swiss World Atlas interactive provides tools to display block diagrams for limited territories as one of the main forms of interactive 3D visualisation. In this article, we will show the capabilities for visualising glacier changes by means of traditional and interactive 2D maps. The advantages and limitations of different 2D representations will be shown and compared with 3D visualisations. We present an overview of the workflow necessary to obtain a digital elevation model from a traditional 2D map with automatic vectorisation. With the comparison of at least two digital elevation models and using 3D visualisation, it is possible to show not only the changes in length, but also in height. In an outlook we will propose ideas on future developments and functions, which could be implemented for the interactive 3D visualisation of glacier changes.

**Keywords:** 3D-Visualisation, Glacier Change, Swiss World Atlas interactive

## 1. Introduction

Glaciers already react to small climate changes with clearly visible consequences. The observation and reconstruction of these changes has had a long tradition in Switzerland. For more than forty years, data on glacier fluctuations in the Swiss Alps have been collected and evaluated by the Glaciology Section at the Laboratories of Hydraulics, Hydrology and Glaciology (VAW) of ETH Zurich. (VAW 2013)

If altitude records of glaciers for different years are available, it is possible to make analysis about the glacier change. The collected information constitute a sound basis for the understanding of past climate conditions, playing also a significant role in the assessment of today's climate situation and contributing to the scientific interpretation of such phenomena. The com-

plete altitude records of an entire glacier are of particular interest to this field of research. Nowadays these records exist in the form of digital elevation models. Usually the data are acquired using aerial photographs, radar interferometry, or light detection and ranging (Lidar). However, glacier surface topography from earlier times is often reconstructed from old maps.

## **2. Swiss World Atlas interactive**

The Swiss World Atlas interactive (SWAI) is a web-based school atlas which was launched as a research project by the Conference of the Directors of Education of the Swiss Cantons (EDK) in addition to the printed version. This atlas is being developed at the Institute of Cartography and Geoinformation of the ETH Zurich. The well-known general and thematic maps from the printed edition were improved, enriched by additional editorial work, and complemented with interactive functions such as zooming, querying objects, layer visibility, saving and exporting map extracts. (SWAI 2010)

In addition to those interactive functions, which provide an added value for the printed atlas, the SWAI contains supplementary representation types such as a virtual globe, the block diagram, or illustrative models. A block diagram represents a small-scale landscape cutout. With this 3D representation, the terrain can be correctly interpreted and the orientation and perception can be facilitated. The addition of navigable block diagrams into school atlases allows discovering geographically interesting areas in a new, attractive way.

## **3. Map types**

The International Cartographic Association (ICA) defines a map in general as “[...] a symbolised image of geographical reality, representing selected features or characteristics, resulting from the creative effort of its author’s execution of choices, and is designed for use when spatial relationships are of primary relevance” (ICA 1996).

### **3.1. Web maps**

Maps have changed in many ways since they were first used. During the last centuries, paper was the most common medium for depicting and distributing maps. Printed maps are at a disadvantage as they are static and customised settings to the user’s needs are not possible. However, in a world driven by digital communication, information is less and less shared through paper. The largest part of information is generated and shared through computers.

Thus, starting in the late 1960s, cartography has encountered a major technological change and the indispensable means has become the Computer (Slocum et al. 2009). Many traditional cartographic tasks have been replaced by computer processing steps and Geographic Information Systems (GIS) are not only used for data preparation, but also for data presentation. The functionality of maps has been greatly advanced by technologies simplifying the overlay of georeferenced, thematic data onto existing base maps.

Interactivity is a fundamental feature of a web application. It comprises the information flow between the user and the computer in both directions. A user can not only manipulate the program flow to a certain extent, but also information can be queried. This query options should be provided in a selective, intuitive and associative way. The interactive functionalities of an application have to be apparent so that the user is able to intuitively interpret their functions at a glance and without any help. In addition, the users should have the possibility to choose which interactions they want to activate.

Today, digital elevation models for all Swiss glaciers are available. This progress led to many new possibilities in the analysis of height changes and dynamics for the whole glaciated area. Innovative web mapping of this data using methods of modern thematic cartography became a challenging and delighting subject.

### **3.2. Maps in the Swiss World Atlas interactive for visualising glacier retreat**

Interactivity in the SWAI is realised by different instruments. For example the user can zoom in and out, respectively to increase or decrease the scale. He can turn on and off layers e.g. to influence the complexity of a map. For further use he can save, copy, and export maps. (SWAI 2010)

To illustrate the thematic of glacier retreats in the SWAI, visualisations for two alpine regions have been created: namely the region in the north of the Matterhorn with the Zmutt Glacier and the Bernina region with the Tschierva Glacier and Roseg Glacier. For both regions we generated block diagrams as well as interactive 2D maps. To visualise the glacier retreat and calculate the differences we used the data from the first edition of the Swiss national maps 1:50'000 (1930) and current data from 2008.

## **4. Workflow – from a traditional 2D map to a digital elevation model**

### **4.1. Step 1: Colour separation**

In order to obtain a digital elevation model (DEM) from a traditional 2D map we need all the available height information (contour lines and spot heights). Regarding the next step, the automatic vectorisation, the input map has to be binary. With the *colour separation*, a tool in ADOBE PHOTOSHOP, it is possible to create separate documents for each colour needed. Via *colour separation* one can enhance the contrast of an image. Multiple channels can be used to select certain areas in the image using the colour information of each pixel. Through the removal of the background and the use of the median filter the unnecessary visual elements (e.g. debris) are largely eliminated.

### **4.2. Step 2: Vectorisation**

Vectorisation means that scanned images are converted into vector-based feature layers. In the manual method, map elements (in raster format), such as contour lines are digitised interactively, which is very time-consuming. With the tool *ArcScan* in ARCGIS the colour separated documents can be automatically vectorised. The conversion from raster data to vector features is based on user-defined settings. Although vectorisation is an automatic procedure, a manual post processing is still necessary. During the vectorisation process, not only the required height information is vectorised but all the information which is available in this specific colour. For the blue colour for example also the crevasses, the rivers and the blue labelling will be digitised.

### **4.3. Step 3: Attributing**

To generate a DEM, every single feature (contour lines and spot heights) needs an attribute with its height information. Generally, this step is performed manually. However, to facilitate this work a semi-automatic tool was written. The advantage of this tool is that not every contour line has to be attributed manually. By creating profile lines which intersect the contour lines and the specification of the level of the lowest line as well as the equidistance, the other contour lines will be labelled automatically.

### **4.4. Step 4: Digital Elevation Model**

In this final step, a digital elevation model is generated using all the detected height information. In ARCGIS there are several possibilities for the interpolation of height information for a DEM. One of those is *Topo to Raster*. This tool was specifically designed for the creation of hydrologically

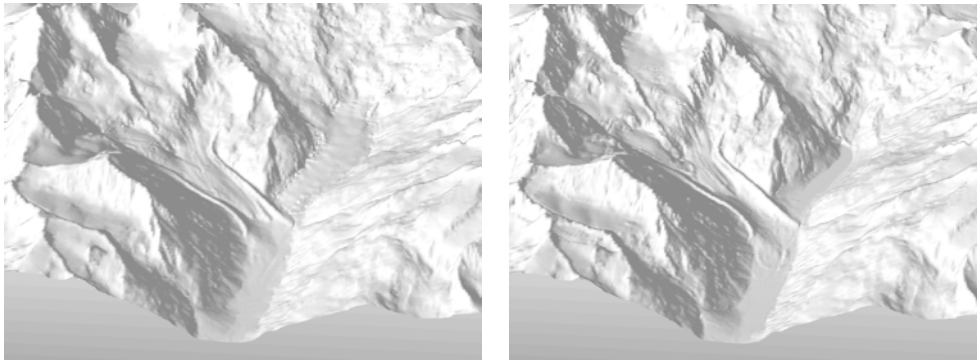
correct DEMs. The *Topo to Raster* tool interpolates the input height values while taking into account a connected drainage structure as well as correct representations of ridges and streams. Thus, this is the only ArcGIS interpolator which has been especially conceived for the input of contour lines. Moreover, in addition to line data, point or polygon data can be specified as input data as well.

## 5. Visualisation of glacier retreat

Using the aforementioned workflow for each region, two different DEMs were generated. With the implementation of these DEMs in the SWAI, we can display the height information in a block diagram. In the following sections different visualisations based on a block diagram will be discussed.

### 5.1. Visualisation with different DEMs

One of the most basic ways to show the melting of a glacier is to display different DEMs. If several DEMs for a specific area exist or have been created, they can be easily integrated in a block diagram (*Figure 1*). With radio-buttons in the legend of this atlas, the user can choose which DEM will be shown on the block diagram. By repeatedly switching between the DEMs rapidly (“flickering”), the change of the landscape and the melting of the glacier are clearly visible.

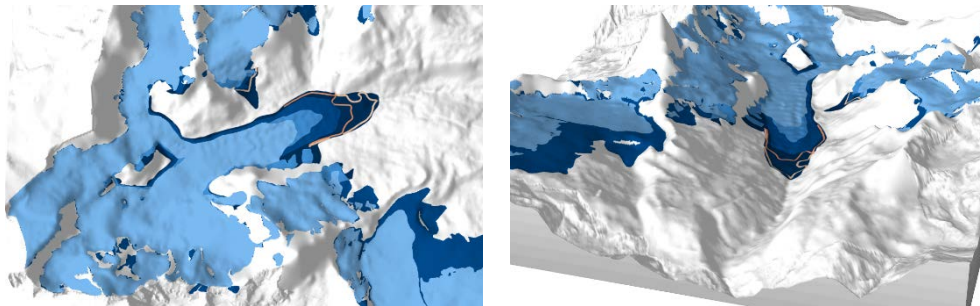


**Figure 1.** Visualisation of the created DEMs for the Bernina region in a block diagram (left: 1935, right: 2008) (Bruengger 2012)

Unfortunately, only one year at a time can be displayed in this view. A comparison of different years becomes rather difficult. It only makes sense to view an elevation model as a static image, if the interesting region is in the foreground. For the visualisations in the next section, these block diagrams are taken as a basis.

## 5.2. Visualisation of the glacier extent with coloured areas and lines

For 2D-maps, colours are often used in the form of lines and areas to represent the extent of the glacier (*Figure 2*). By the superposition of multiple time periods, the map can quickly become complex and confusing. But, even with such a presentation, interactivity provides significant benefits. The user can choose which time periods he wants to display and compare.



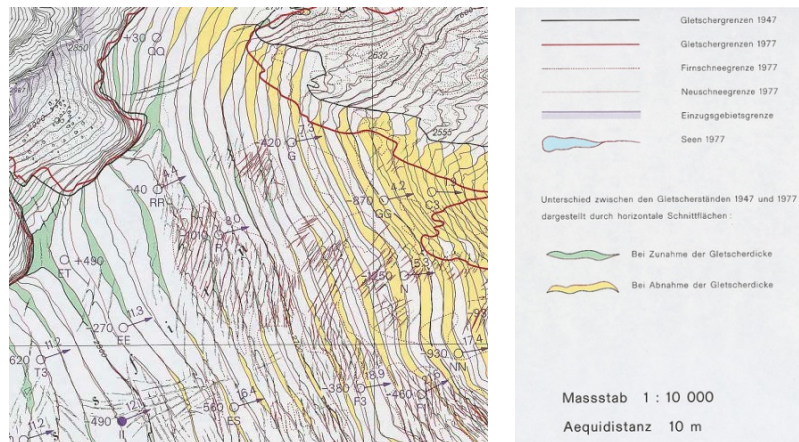
**Figure 2.** Different glacier extents shown with coloured areas and/or lines in a 2D map (left) and in a block diagram (right) (Bruengger 2012)

Surely, this representation can be applied to a 3D map (block diagram). However, if the map would be static, there would be no big advantage when compared to a 2D map. In a 3D visualisation certain areas could be occluded, for example by mountains in the foreground. In an interactive map, however, the user can rotate the block diagram and can interpret the terrain much easier.

## 5.3. Visualisation of height changes

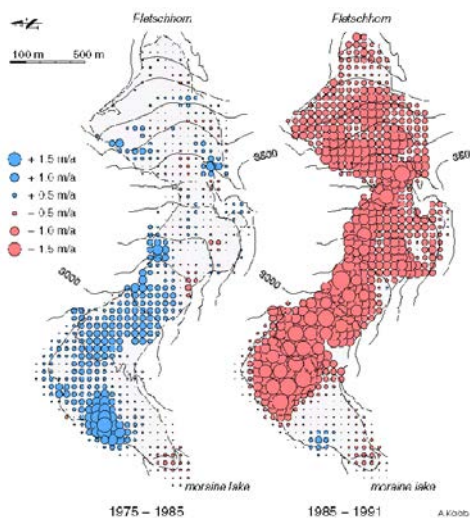
With the creation of multiple DEMs of different years, it is possible to calculate the decrease (or rarely increase) of a glacier. These differences can then be superimposed as a layer on another map.

By combining the contour lines of two different time states, areas arise where the height has changed (*Figure 3*). Those surface-differences are called contour bands. The negative and positive areas of height change differences are shown in two different colours depending on whether it is an increase or decrease.



**Figure 3.** Changes in height showed with contour bands for the Griessfirn (SWISS-TOPO and VAW ETHZ 1981)

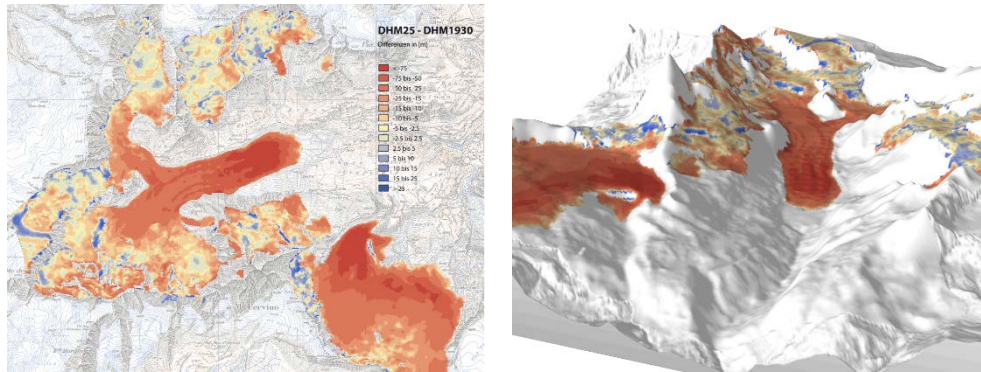
Kääb (1999) chose a different way to represent the height changes. He represents the height difference on the glacier area with circle symbols: the bigger the amount of change, the larger the circle (*Figure 4*). Depending on the colour of the circle, a decrease or increase in the given time period can be detected.



**Figure 4.** Thickness change of Gruben glacier from 1975 to 1991 (Kääb 1999)

Another method to visualise the changes in height is to show the calculated differences with different colours. This kind of representation is widely used in glaciology. In this field it is common to show the decreases in red hues and the increases in blue hues. Areas in which the height has only lightly

changed are only coloured with one neutral colour, regardless of whether it is an increase or decrease.



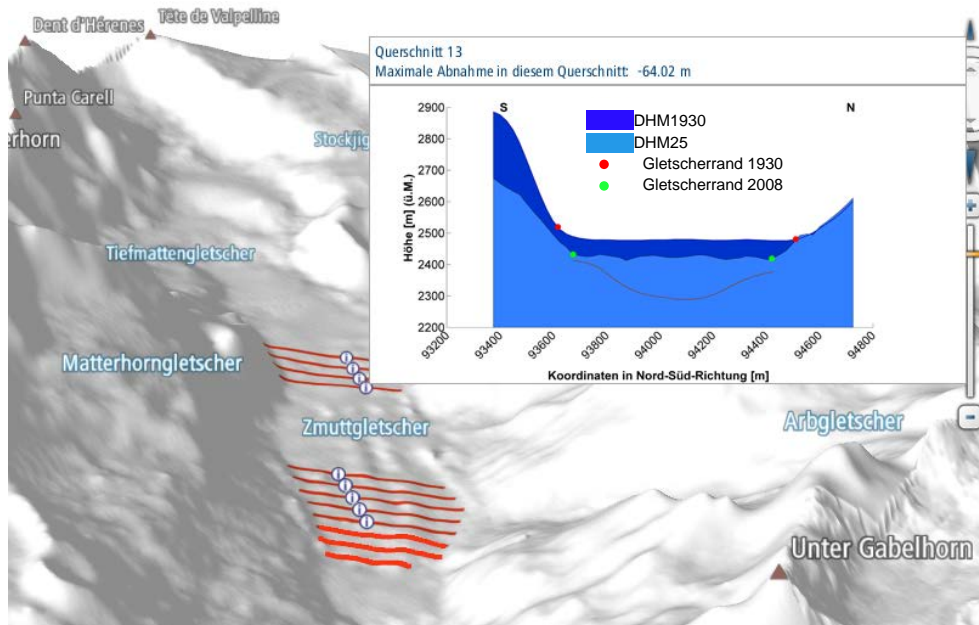
**Figure 5.** Coloured representation of the height difference between two DEMs (extent of the year 2008 (heights of DHM25) minus extent and heights of the year 1930) (Bruengger 2012)

This coloured representation of the differences between two DEMs in a block diagram provides only a small added value to the 2D representation (*Figure 5*). Especially untrained map readers can better interpret the structure of the landscape around the glacier in a 3D block diagram. However, a user of those images is interested usually only in the changes (decreases or increases) which occurred on the glacier. This issue can be demonstrated in a 2D map as well.

#### 5.4. Visualisation of profiles

Another representation to illustrate the change of the glacier is the use of cross-sections. This allows seeing not only the differences in height, but also the loss of volume, the thinning, can be clearly shown. Nevertheless, this representation is only possible if an elevation model of the surface of the glacier and also of the glacier bed exists. Moreover, the capture of the underground of a glacier, particularly in earlier times, could be done only at great expense. This is one of the reasons why such data are available only for selected areas. So, if such height data of the glacier surface and the shape of glacier bed are available, profiles can be calculated. In *Figure 6*, we can clearly see, that the magnitude of the ablation can be better interpreted.





**Figure 6.** Profile through the Zmutt glacier (Bruengger 2012)

Since the representation of the profile is a picture, the advantage of a 3D view is again only marginally better than that of a traditional 2D visualisation. But by means of the interactivity, profiles can be turned on or off and the user can select which profiles he wants to compare.

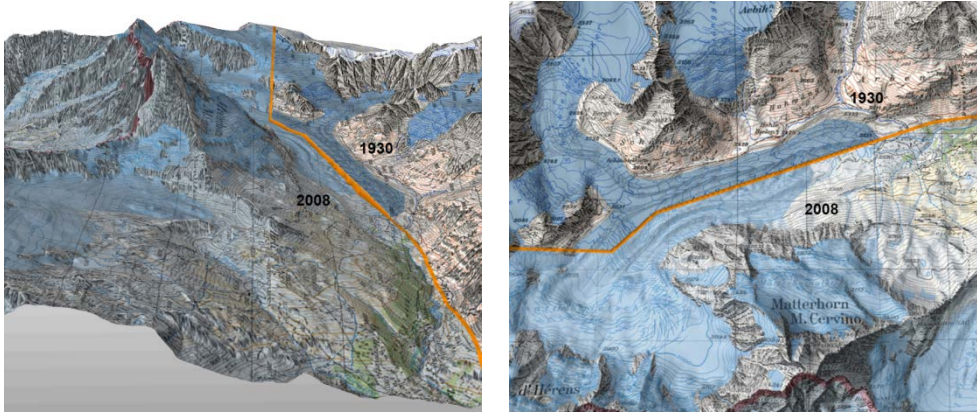
The profile diagram which can be seen in *Figure 6* was implemented in the SWAI as a so called image-tooltip. Once the mouse is moved over the info icon or the profile-line, the corresponding profile image appears. By clicking on the image, it will open. This makes it possible to compare multiple profiles against each other. With these (image-)tooltips further information about the glacier can be presented to the user.

### 5.5. Visualisation of two different DEMs in one block diagram

In order to even better recognise the significant glacier retreat, the idea has arisen to show two different elevation models in a single block diagram. A combination of two DEMs interactively is not yet possible in the SWAI.

To evaluate possibilities of such a connection, a new DEM was created in the framework of the master thesis “Gletscher im Mattertal” (Bruengger 2012). It represents in the northern part the height information of 1930 and, in the southern part, those of 2008 (*Figure 7*). The border between these two elevation models was chosen along a longitudinal profile. With this innovative representation, the changes of a glacier can be depicted in a

more attractive way and, at the same time, change in length and also in height can be visualised.



**Figure 7.** Combination of the DEM from 1930 in the northern part of this area and from 2008 in the southern part (Bruengger 2012)

## 6. Conclusion and Outlook

Although the creation of a digital elevation model out of an old map can be efficiently done with the described approach, the work flow could still be improved. In particular, there is potential for enhancement in the step of colour separation.

To visualise a small-scale landscape extract, the block diagrams implemented in the SWAI offer an appropriate visual environment. The changes of glaciers could be presented with different layers in various ways. By combining at least two different elevation models in a single block diagram, a new representation has been created showing the retreat of glaciers in length and also in height.

Proposals for possible further functions, which would greatly expand and optimise the representation in a block diagram, are the following:

- Representation of height differences in the form of columns in 3D: The Keyhole Markup Language (KML) allows creating and displaying several kinds of shapes in 2D and 3D, and mapping them into a block diagram or on a virtual globe. Using this technique, the calculated differences between two DEMs could be visualised not only with different colours as it is shown in *Figure 5*, but also with 3D columns, which extrude from the ground.  
User defined location of cross sections: The user can interactively select a location on the glacier, where the profile of the glacier sur-

face and glacier bed will be shown. In the framework of the master thesis “Gletscher im Mattertal” (Bruengger 2012), different selected profiles of the Zmutt glacier were pre-processed. These cross sections were implemented in the block diagram as image-tooltips. Even if this is a static approach, it is a performant realisation also when using via the Internet. The here proposed interactive and on-the-fly calculation and display of cross sections requires significant processing power and/or bandwidth from the system.

Animations of glacier extents for specific time periods: By stringing together static images, it is possible to simulate movement. In this way, data of at least two situations from different years can be used to illustrate the movement. Using morphing techniques, the states in between could be interpolated.

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